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Evaluating Human Operator Performance in a Fully Immersive Virtual Reality Environment

Dr. J. Bernard, Iowa State University

Abstract

The Virtual Reality Applications Center is a national leader in the increasingly important field of applications of virtual reality to the challenges of engineering and science.

This DURIP contract provided peripheral equipment for VRAC's C6, a 360-degree immersion device used to display synthetic environments in real time. C6 includes six stereoscopic screens, a three-dimensional sound system, and wireless technologies.

C6, which cost over $5 million to design and build, was made possible by support from the Air Force of Scientific Research, the National Science Foundation, Iowa State University and private industry. DURIP funds helped purchase a tracking system, networking hardware, and storage devices crucial to the operation of the system. We are now using the C6 on two major defense related projects applying virtual reality interfaces to improve operational readiness and situational awareness. The first of these projects, sponsored by the Air Force Research Lab's Human Effectiveness Directorate, is investigating the use of collaborative computer immersion to recreate a Joint Battlespace. The second is a multi-year collaboration between a VRAC research team, the Iowa National Guard, and the Iowa Technology Center. The objective of this effort is to investigate, create and evaluate the use of immersive interfaces as tools to improve the operational readiness of Iowa National Guard staff, both Army and Air.

Evaluating Human Operator Performance in a Fully Immersive Virtual Reality Environment

Sponsored by:
Department of the Air Force
Office of Scientific Research

F49620-00-1-0267

Final Technical Report

Jim Bernard, Director
Carolina Cruz Neira, Associate Director

Virtual Reality Applications Center
Iowa State University

March 15, 2002

1.0 Introduction

The Virtual Reality Applications Center is an interdisciplinary research center administered by the Institute for Physical Research and Technology at Iowa State University. VRAC has become a national leader in the increasingly important field of applications of virtual reality to the challenges of engineering and science.

VRAC is committed to providing our researchers with the widest possible range of immersive environments so we can assess, as part of our research, the appropriate level of immersion for each task. To that end, VRAC equipment currently on line includes:

Computers

1 SGI Onyx2 with six IR2 Engines (24 R12000 Processors)
2 SGI Power ONYX Multi-Pipe Infinite Reality2 Engines (12 R10000 Processors ea.)
4 SGI Dual Processor Octane MXI
2 SGI ONYX Reality Engine2
2 SGI Origin 200
4 SGI O2s
1 SGI Challenge DM
11 SGI Indys
6 PC systems

VR Peripherals

ible Screen Configuration Virtual Reality System MD-Flex Barco Reality 909 Base Proposal
ot Micro Movemaster EX MELFA
sion Datavisor HMD
ual Research V8 HMD
sAble Technologies 1.5A PHANTOM Haptic Device
ual Technologies Cyberglove
espace Labs Pinch Gloves (5 sets)
espace Labs BOOM3C
eoGraphics CrystalEyes Stereo Glasses
Vision Stereo Glasses
tial Systems Powerball
itech 3D Mouse
itech Position Head Tracker
ension Technologies Flock of Birds (3)
ion Star Trackers (2)
less Pointer Devices (2)
ersion Interface Boxes (3)
ersion Probe
a 560 6DOF Manipulators (2)
Level Control Consoles (2)
on Platform: 6 DOF w/2000 lb. capacity, approx +/-1 ft. travel in each direction, +/- 30 degrees per axis

Video Equipment

6 Barco Graphics 909 Projectors
5 Barco Graphics 1208 Projectors
1 8x8 Video/Audio Extron Switcher
1 16x16 Extron Audio switcher
1 32x32 Extron video switcher
26 RGB 112 Extron Das
13 Cybex Longviews (copper)
10 Lightwave VDE (fiber)
JVC CR-850U, 3/4" VCR
JVC BR-S811U, SVHS/VHS VCR
JVC VM-R190SU, Color Monitor
Sony Trinitron, Color Monitor

Software

ACIS
Adams
AudioWorks
ANSYS
DADS
DragonDictate
Ensight
Fieldview
Fluent
I-DEAS
IRIS CaseVision/Workshop
IRIS Inventor
IRIS Performer
Transom Jack
MATLAB
ModelGen, MultiGen II
Multigen Creator
PhotoShop
Polytrans
ProEngineer
SAMM
Starcd
Softimage
Softimage XSI
VisLab
VR Juggler
Voxmap PointShell
WorldToolkit

VRAC supports two different head mounted displays, an nVision VGA Datavisor HMD and a Virtual Research V8 HMD. VRAC has also recently added a Barco Baron stereoscopic projection table providing portable high resolution stereoscopic display on a 60-inch rear-projected screen. The Baron table is a desk size device that can be oriented in any position from traditional desk orientation to vertically. The projection surface is tracked and provides real time 3D graphic display.

To provide full body immersion, VRAC has two state of the art immersive rooms, the C4 and the C6 and a 250 seat stereo projection auditorium:

- The C4, which includes three walls and a floor supporting real time display. The C4 has a flexible configuration – the side walls can be set at any angle with the front wall from ninety degrees, the traditional CAVE configuration, to a thirty-six foot long flat wall.
- The C6, our most immersive environment. The C6 is a ten foot by ten foot cube which surrounds its users on all sides with real time 3D interactive graphics.
- The Lee Liu Auditorium. This unique auditorium uses passive stereo to display two simultaneous side-by-side video signals in 3D to an audience of up to 250 people.

This equipment now supports the research of about 25 faculty researchers and about 75 graduate students. Total dollar value of ongoing research projects in VRAC is just over $10 million. The Appendix lists ongoing research contracts and their principal investigators.

By most any measure, VRAC is now a world leader in VR applications. Attaining such a position is the work product of many people here at ISU plus the help of many sponsors who have shared our vision and provided resources to support our work. We are grateful to AFOSR for their continuing support.

This DURIP contract provided peripheral equipment for the C6. The next section of this report provides some context by describing the C6 and gives details of how the AFOSR support was used. Then section 3 of this report shows how this equipment is supporting defense applications.

2.0 The C6–a Fully Immersive Virtual Reality Environment

The C6 is a 360-degree immersion device used to display synthetic environments. It is based on research conducted by Dr. Carolina Cruz-Neira. The device is comprised of six stereoscopic screens, a three-dimensional sound system, and wireless technologies. Using this device, a user is able navigate through and manipulate virtual worlds. The C6 debuted on June 19, 2000.

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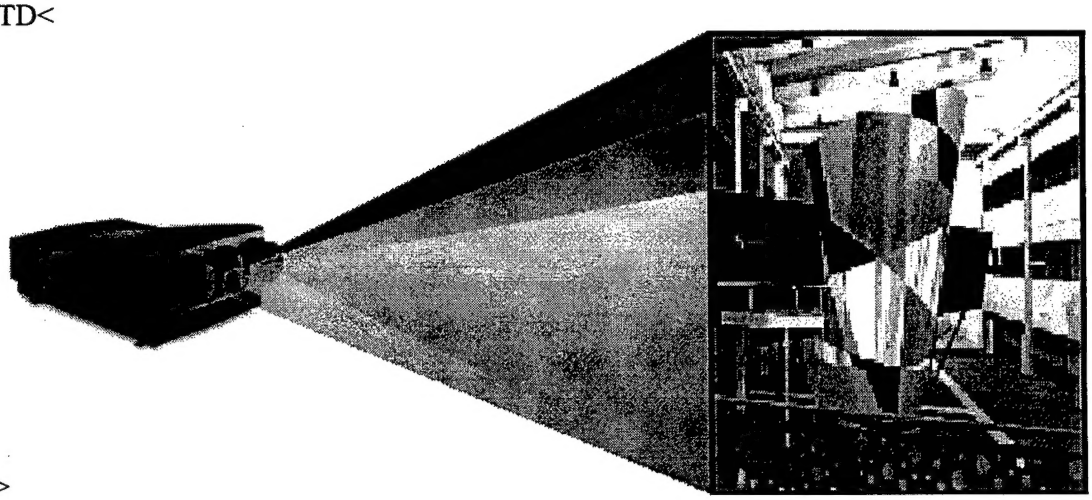

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The user stands in a 10 by 10 by 10 foot arena with rear-projected screens. Because space is a limitation, the ceiling and floor images from the projectors are reflected off of mirrors before reaching the screens. The C6 framework was designed by MechDyne and Iowa State University researchers.

The computer image generator system is a SGI Onyx2 InfiniteReality2 Monster. It includes six InfiniteReality graphic displays, 24 R12000 processors, 12 gigabytes of memory, and access to large disk I/O and gigabit ethernet networking. The Ascension Technologies wireless MotionStar magnetic tracker is used to monitor the user's position and orientation. This tracker maintains the user's current position used to calculate a true stereoscopic perspective view while allowing one to freely move into and around objects that appear within the virtual space. The tracker also tracks input devices, such as a wireless wand or glove. Stereoscopic perception is achieved using light-weight liquid-crystal active polarized shutter glasses. Speakers are mounted around the C6, giving participants the added sense of immersion through surround and localized sound.

The total cost of the design and build of the C6 was over $5 million. This was made possible by support from:

- Air Force Office of Scientific Research
- Ascension Technologies
- Barco
- Boeing Company
- College of Engineering, ISU
- Deere & Company
- Institute for Physical Research & Technology (IPRT), ISU
- Iowa State University
- MechDyne Corporation
- National Science Foundation
- Procter & Gamble
- Silicon Graphics, Inc.
- And the students, faculty and staff of VRAC

AFOSR provided $216K for C6 through this DURIP grant. With these funds we purchased:

- Motion Star Wireless 6-DOF tracking system
- Fibre channel disk chassis, includes:
    - second fibre channel loop,
    - controller card,
    - power supply,
    - rackmount original fibre channel raid vault,
    - ten 36GB 7200 RPM Dual port fibre channel raid disk for origin FC raid
- Sony Betacam recorder/player
- Video camera
- 2 NTSC converters
- SGI Origin 200 System
- Fiberoptic cable
- Video/audio keyboard serial extension units (11)

- Extron video matrix switcher
- Extron video converters
- Extron audio switcher
- Pinch Glove System
- 8 port Ethernet S10 Terminal Server

3.0 Defense-Related work in the C6

Researchers at VRAC are working on two major defense related projects applying virtual reality interfaces to improve operational readiness and situational awareness. The first of these projects, sponsored by the Air Force Research Lab's Human Effectiveness Directorate, is a two-year investigation of the use of collaborative computer immersion to recreate a Joint Battlespace. The Virtual Battlespace currently under development is a platform for experimentation to determine the positive impact that immersion can have on battlespace management. The project objective is the development and evaluation of a data synthesis and visualization system for battle managers. The system facilitates multi-user, collaborative interaction between participants at a variety of levels of immersion.

The current phase of the investigation involves the development of a multi-user, collaborative system to allow interaction between participants at a variety of levels of immersion. The system will facilitate simultaneous interaction between multiple participants, playing distinct roles at distinct levels of immersion. Combining a traditional 2D desktop user, a user at an immersive desk, a fully immersed user in the C4 or C6, and a group of from 10-200 users in the VRAC stereo auditorium into a common environment will provide us a test bed to evaluate how levels of immersion can be used to increase task performance in a battle environment. Some initial results of this work have been summarized in a paper to be presented at this years International IITSEC conference in Lille, France. (Innovative C2 Training Solutions For Air Force Modular Control Systems, Brooks, Breitbach, George)

The second project is a multi-year collaboration between a VRAC research team, the Iowa National Guard and the Iowa Technology Center. The objective of this effort is to investigate, create and evaluate the use of immersive interfaces as tools to improve the operational readiness of Iowa National Guard staff, both Army and Air. Working with domain experts assembled by the Guard and the Iowa Technology Center, Iowa State University (ISU) is leveraging the considerable hardware, software and intellectual resources of ISU's Virtual Reality Applications Center (VRAC) to develop immersive training applications that provide Iowa Guard personnel with a greater breadth and depth of situational experience than would be possible without simulation. Using state of the art computer visualization, ISU is showing how the next generation of human-computer interfaces can be incorporated as an integral and effective component of the system for preparing Iowa Guard personnel for their role in the warfighting machine of the coming decades. The effort is currently directed towards training in the area of command and control, providing Iowa Guard personnel with comprehensive and flexible training simulations. The result will be more realistic training that is cost effective.

4.0 Summary

The purchase of tracking gear and other equipment through DURIP support helped bring the C6 on line in June 2000. Since that time, work with the C6 and the other VRAC immersive environments have increased to provide support for a wide range of ongoing work, including exciting and innovative defense contracts.

We are grateful to AFOSR for their continuing support.

Appendix

Ongoing Research Projects

Sponsor	PI	Term	Title	Co-PIs
Air Force Office of Scientific Research	James Bernard	4/1/2001 to 3/31/2002	A Virtual Reality Applications Facility for Visualization of Joint Battlespace	C. Cruz-Neira
Air Force Research Lab (AFRL/IFB)	James Bernard	8/21/2000 to 12/31/2002	Visualization of the Joint Battlespace	C. Cruz-Neira; H.-A. Pham
Air Force Research Lab (AFRL/IFB)	James Bernard	2/22/2002 to 12/31/2002	Visualization of the Joint Battlespace (continuation)	C. Cruz-Neira; A. Sannier
Alliant Energy	Kenneth M. Bryden	8/15/2000 to 8/14/2003	Computational Modeling of a Tangentially Fired Pulverized Coal Furnace: Phase 2	
Alliant Power	Kenneth M. Bryden	11/1/1998 to 12/31/1999	Computational Modeling of a Tangentially Fired Pulverized Coal Furnace: Phase I	
Battelle/TACOM	Carolina Cruz-Neira	9/22/2000 to 11/20/2001	Immersive Collaborative Environments	
Bechtel BWXT Idaho, LLC	Greg Luecke	07/31/01-12/31/01	Comparative Visualization of Experimental and Computational Biomass Separation Data	
Cornell University (NSF)	Carolina Cruz-Neira	10/1/1999 to 9/30/2002	A Two-tier Computation and Visualization Facility for Multiscale Problems	
Deere & Company	James Bernard	11/1/2001 to 10/31/2005	Synthetic Environments as Enabling Technology for Product Development: Phase	K. M. Bryden; D. Cook; C. Cruz-Neira; J. Dickerson; A. Kelkar;

			3 (continuation)	G. Luecke; J. Vance
Deere & Company	James Bernard	11/1/2001 to 10/31/2002	Synthetic Environments as Enabling Technology for Product Development: Phase 3	K. M. Bryden; D. Cook; C. Cruz-Neira; J. Dickerson; A. Kelkar; G. Luecke; J. Vance
Department of Energy	Kenneth M. Bryden	10/1/1999 to 9/30/2002	Development of Virtual Power Plants	
Ford Motor Company	Judy Vance	5/6/1998 to 9/9/2001	Evaluating the Use of Haptics in Virtual CAD Tasks	
Fuel Tech, Inc.	Kenneth M. Bryden	8/15/2001 to 8/15/2005	Development of Rapid Solutions for Reacting Flows	
Indian Hills Community College (NSF)	Kenneth M. Bryden	8/15/2001 to 6/30/2004	Learner Connections in Biotechnology: Virtual Bioprocess	
Iowa Department of Public Defense	Adrian Sannier	4/1/2001 to 9/30/2001	Military Applications of Immersive Environments	J. Bernard; C. Cruz-Neira
IPRT	Kris Bryden	11/1/2001 to 6/30/2003	An Atonal Approach to Sonification of Scientific and Engineering Data	D. Ashlock; K. M. Bryden; A. Sannier; P. Schnabel
IPRT	Li Cao	11/1/2001 to 6/30/2002	MEMS Fabrication, Assembly, Performance, and Cost Tradeoffs with Virtual Reality Design Tools	
ISU - Center for Teaching Excellence	A. Whitney Sanford	7/1/2001 to 6/30/2001	Virtual Religion: Integrating Information Technology into the Religious Studies Curriculum	C. Cruz-Neira

ISU-Special Research Initiation Grants Competition	Anne Deane	1/1/02-12/31/02	Ashes to Ashes Driving Project	C. Cruz-Neira
John Deere & Company	James Bernard	9/1/1998 to 8/31/2001	Synthetic Environments as Enabling Technology for Product Development: Phase II	J. Vance; G. Luecke; C. Cruz-Neira
John Deere Construction Equipment Company	Julie Dickerson	8/25/2000 to 8/25/2001	Phase I: Visualization of High Dimensional Control Surfaces	D. Cook; C. Cruz-Neira; H.-A. Pham
John Deere Foundation	Judy Vance	4/6/2001 to 4/5/2002	John Deere Foundation Gift	
National Science Foundation	Chan, Chiu-Shui	1/1/2001 to 12/31/2003	Utilizing Three-Dimensional Data in a Virtual Urban Environment to Support and Evaluate Planning Decisions	C. Cruz-Neira; R. G. Mahayni; D. Shinn; I.-S. Suen
National Science Foundation	Dianne H. Cook	10/15/1999 to 9/30/2002	Interactive and Dynamic Visual Overviews of Large Multi-Dimensional Data	V. Honavar; L. Miller
National Science Foundation	William Gallus	11/1/01-10/31/03	A Virtual Tornadic Thunderstorm to Enable Student-Centered Learning About Complex Storm-Scale Atmospheric Dynamics	C. Cruz-Neira; C. Cervato
National Science Foundation	Judy Vance	8/1/1996 to 7/31/2002	REU: A Career Development Plan: Research and Teaching	
National Science Foundation	Judy Vance	8/15/1996 to 7/31/2002	A Career Development Plan: Research and Teaching	

National Science Foundation	Judy Vance	10/1/2000 to 9/30/2003	Interactive Product Development in a Virtual Environment Utilizing Haptics	
National Science Foundation	Judy Vance	8/1/2001 to 9/30/2003	Interactive Product Development in a Virtual Environment Utilizing Haptics (RET)	
National Science Foundation	Julie Dickerson	1/1/2001 to 12/31/2003	Wireless Multimedia Communications for Virtual Environments	D. Rover; C. Cruz-Neira; R. Weber
National Science Foundation	William Gallus	2/1/2002 to 1/31/2003	A Virtual Tornadic Thunderstorm to Enable Student-centered Learning About Complex Storm-Scale Atmospheric Dynamics	C. Cruz-Neira; C. Cervato
National Training Systems Association	Carolina Cruz-Neira	8/15/2000 to 8/14/2001	Interservice/Industry Training, Simulation & Education Conference Scholarship	
National Training Systems Association	Carolina Cruz-Neira	8/16/2001 to 8/15/2002	Interservice/Industry Training, Simulation & Education Conference Scholarship	
Nonvolatile Electronics, Inc.	Robert Weber	8/16/2000 to 12/31/2001	Ultra Low Power Enabling Technologies for Adaptive Reconfigurable Power Aware Computing and Communications	
Pioneer Hi-Bred	Dan Ashlock	2/21/2000 to 12/31/2001	Visualization of Gene Expression Data	E. Wurtele
Positech Corp	Greg Luecke	2/4/2000 to 5/14/2001	Automatic Control for Operator Assist in Heavy-load Handling: Phase II	

Procter & Gamble Company	Dan Ashlock	8/3/2000 to 12/31/2002	Bioinformatic Tools for Extraction and Modeling of Signal Transduction Networks	D. Berleant; J. Dickerson; R. Maddux; E. Wurtele
Procter & Gamble Company	Judy Vance	2/1/2002 to 1/31/2003	Exploration of Finite Element Analysis Data in a Virtual Environment	
Procter & Gamble Company	Judy Vance	5/1/2000 to 10/31/2001	Virtual Reality Environment for Fluid Particle Simulation	
Procter & Gamble Company	Judy Vance	9/1/2000 to 6/30/2001	Virtual Reality Environment for Fluid Particle Simulation (continuation)	
Procter & Gamble Company	Judy Vance	10/20/1997 to 6/30/2001	Virtual Prototyping for Interpretation of Analysis Data	
University of Iowa/NADS	James Bernard	8/1/2000 to 7/31/2002	Advanced Simulator Networking for Vehicle and Equipment Distributed Product Design	C. Cruz-Neira; K. M. Bryden
US Dept. of Energy	Kenneth M. Bryden	6/21/2001 to 9/30/2004	Multi-Component Harvesting Equipment for Inexpensive Sugars from Crop Residues	F. Battaglia
Winegard Company	Greg Luecke	4/28/2001 to 4/27/2002	Analysis and Implementation of a Tracking Mobile Television Receiver (continuation)	
Winegard Company	Greg Luecke	4/9/1999 to 4/27/2000	Analysis and Implementation of a Tracking Mobile Television Receiver	